California State Polytechnic University Pomona
Department of Electrical and Computer Engineering

ECE 4869 Power Electronics - Summer 2024

Project

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1. Design of a device or a system

1) Parameters:

For my project, I decided to design a buck converter. A buck converter is a type of DC-DC converter that converts a DC voltage to a different DC voltage level. Oftentimes, they provide a regulated output to satisfy certain requirements. Buck converters reduce the input voltage to a particular lower value that is wanted at the output.

To design a buck dc-dc converter, an inductor, capacitor, resistor, diode, and an electronic device to serve as the switch are needed. The switch is used to turn the circuit on and off to achieve the voltage wanted. The inductor stores energy and acts as a current limiter since the current can't change instantaneously. The capacitor stabilizes the voltage across the load and when fully charged acts like a voltage source. The diode is used to conduct the inductor current when the switch is open. The inductor and capacitor also form a low pass filter.

When the switch is closed, current flows through the inductor then splits to the capacitor and the load. The diode provides a path for the inductor current. The diode is reverse bias which acts as an open circuit.

Since the device/system design must be appropriate/realistic, I decided to draw inspiration from a campus project I was a part of for two years. The project's goal is to design an unmanned ground vehicle capable of rescuing an immobile hiker. The vehicle itself is scaled down in size. I attached a photo below of the 2022-2023 model below.

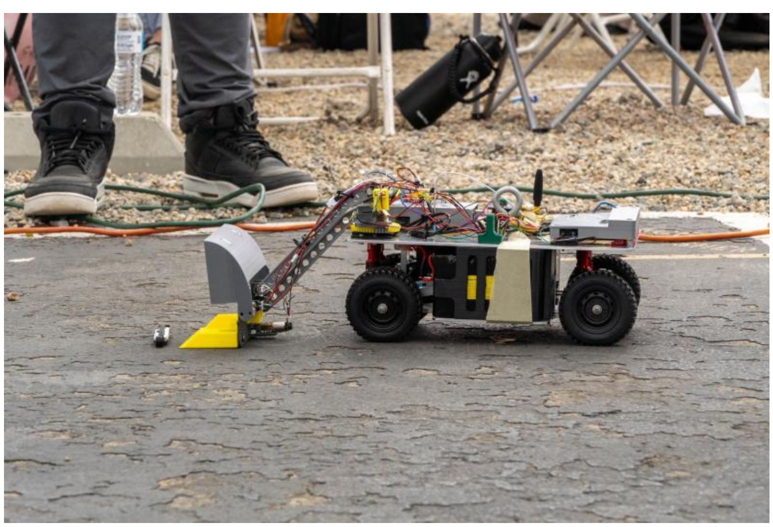

Figure 1: Northrop Grumman Collaboration Project (NGCP) Unmanned Ground Vehicle (2022-2023)

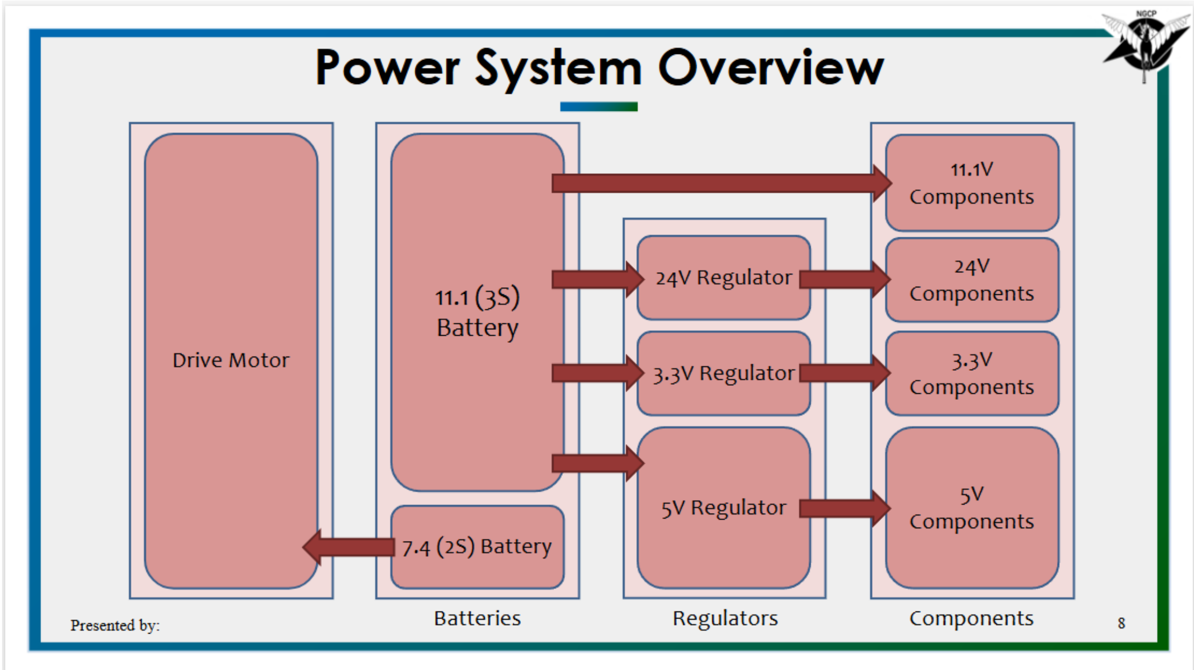

Figure 2: Vehicle Power System Overview

The unmanned ground vehicle's power system used regulators to step down the voltages from one battery that many of the components drew from. The regulator we used for the vehicle is Pololu's [5V, 5.5A Stepdown Voltage Regulator D36V50F5.](#) This voltage regulator allows for an input range voltage from 5.5-50V and steps the voltage down to 5V.

For my design, I decided to make a buck converter that converts an input of 11.1V to 5V. I thought it would be interesting to try to create an ideal buck converter inspired by the portion I outlined in green below. I loosely based my parameters on what would be realistic for a buck converter that could power small – moderate projects from what I gathered working on this project and taking ECE 4869 this summer.

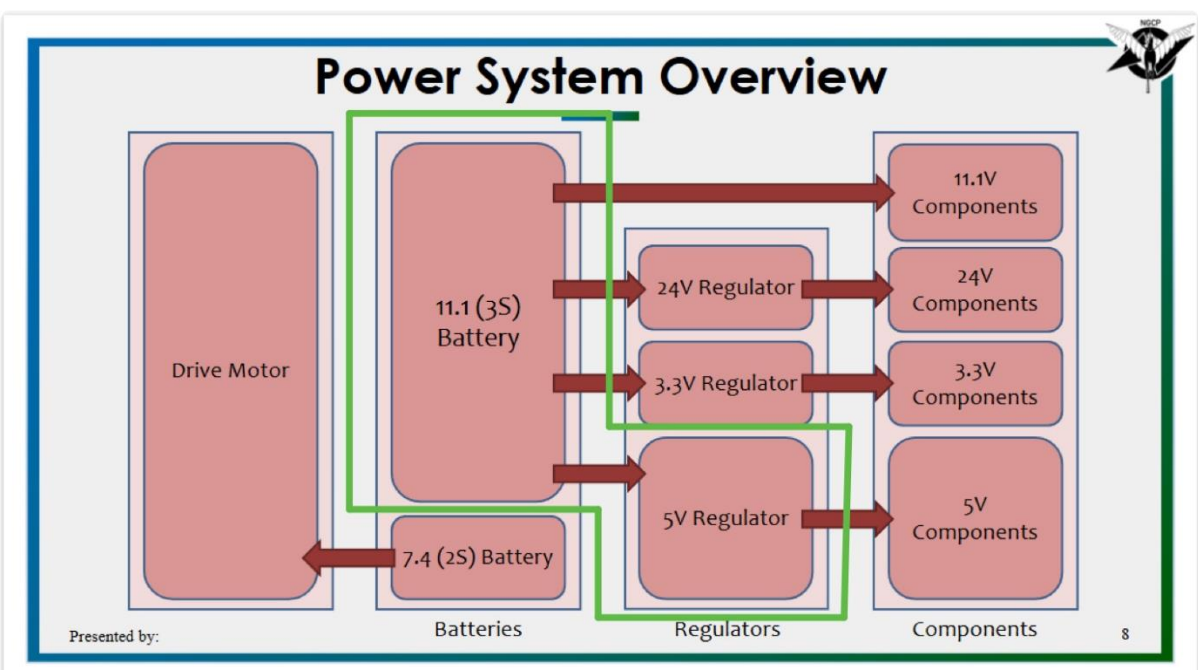

Figure 3: Buck Converter Design Inspiration (11.1V -> 5V)

The parameters I decided to set for my design are:

Input Voltage	11.1V
Output Voltage	5V
Load (Resistor)	20 Ω
Capacitor	4μH
Inductor	13.75μH
Switching Frequency (fs)	500 kHz
Ripple Voltage	0.005V
Duty Cycle	0.45

Table 1: Device/system parameters

2) A Circuit Diagram:

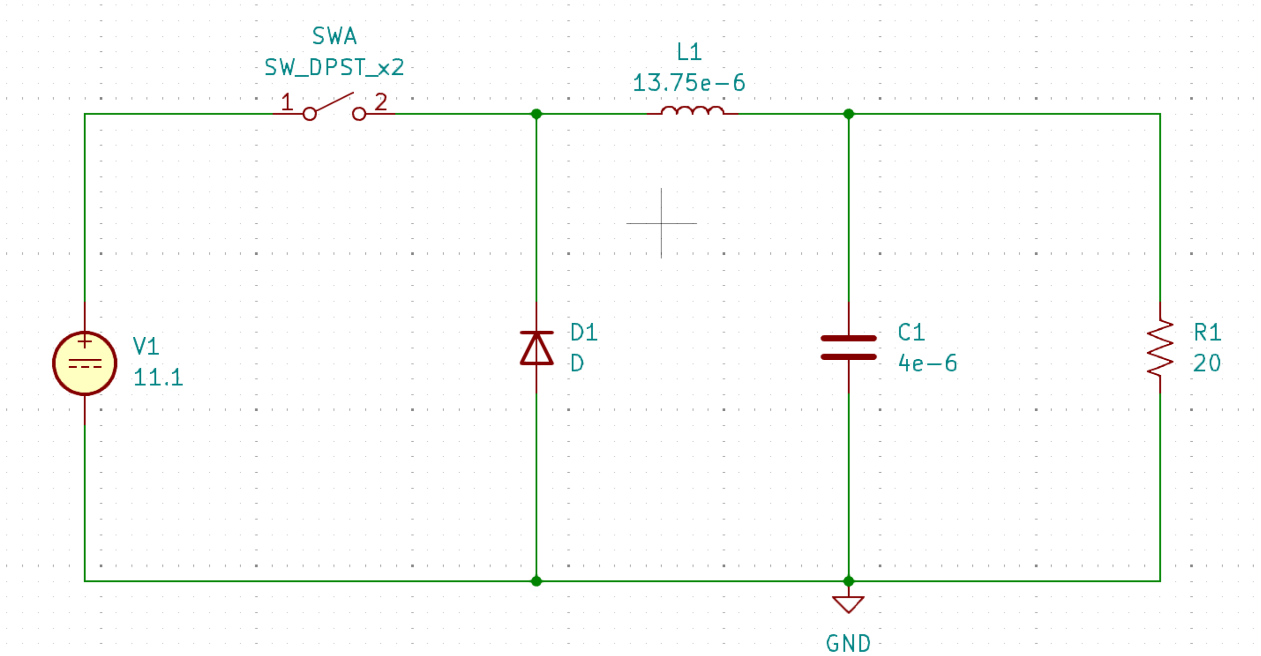

Figure 4: 11.1 to 5V Buck Converter Circuit Diagram

3) Rationale:

Need for the device, benefit, and its applications:

The 11.1 to 5V buck converter I designed could be used for a variety of applications since many electronics run on 5V. A need for a device like this would be to step down an input voltage of 11.1V (perhaps from a LiPo battery or power supply) to power 5V devices.

I chose my buck converter to have an input voltage of 11.1V because LiPo batteries (which are 11.V) are a common battery used by many hobbyists for drones, RC cars, laptops, electric bikes, and photography equipment. I chose my buck converter to have an output voltage of 5V because many electronics run on 5V. Some examples include PIC microcontrollers, Arduino boards, sensors, Bluetooth modules, wi-fi modules, RFID modules, LCDs, LEDs, motors, chips, and much more. The buck converter I designed is beneficial since 11.1V is a common input voltage and many devices run on 5V.

The buck converter I designed could be used for many applications, such as undergraduate and moderate design projects since my parameters are common values that can be replicated in a typical lab setting. For example, the unmanned ground vehicle project that I drew inspiration from had many electronic devices that operated on different input voltages. It was useful to use regulators because it helped save space using one 11.V battery to power one portion of the vehicle. The vehicle had motors, motor drivers, ultrasonic sensors, a camera, and a laser -- many of these operating at 5V.

Reason / rule of thumb for parameter selection:

Input Voltage: 11.1V

- LiPo batteries are 11.1V and are commonly used in various electronic projects/products.

Output Voltage: 5V

- Many electronics require an input voltage of 5V to be powered on.

Duty Cycle:

- $D = \frac{Vo}{Vs} = \frac{5}{11.1} = 0.45$

Load (Resistor): 20 Ω

- I decided to use a 20 Ω load because it is a common resistor value to use in a lab setting and in past homework problems we've gone over in class.

Switching Frequency: 500 kHz

- Some designers consider about 500 kHz to be the best compromise between small component size and efficiency (Lecture 1 - Slide 28)

Ripple Voltage: 0.005

- I used this ripple voltage because it is a common ripple voltage we worked with in past problems and examples.

Inductor: 13.75μH

- $L_{min} = \frac{(1-D)R}{2f} = \frac{(1-0.45)20}{2(500000)} = 11\mu\mathrm{H}$

- (Some designers select a value 25% more than Lmin for inductor, Lecture 1 – Slide 28)
- $L = 1.25L_{min} = 13.75\mu\mathrm{H}$

Capacitor: 4μF

- $C = \frac{(1-D)R}{(8Lf^2)(\frac{\Delta Vo}{Vo})} = \frac{(1-0.45)20}{(8*(13.75*10^{-6})*(500000)^2)(0.005)} = 4\mu\mathrm{H}$

4) Output Calculation:

- $Vo = Vs * D$
- $Vo = 11.1 * 0.45$

- $Vo = 5V$

- Since $\frac{\Delta Vo}{Vo} = 0.005$, Vo should equal 5 which means that $\Delta Vo = 0.025$

- $Vo = \frac{(1-D)*R*\Delta Vo}{8Lf^2C} = \frac{(1-0.45)*20*0.005}{8*13.75*10^{-6}*500000^2*4*10^{-6}} = 5V$

- $Vo = I_oR = (0.25A)(20\Omega) = 5V$

2. Simulation and analysis of designed device/system

1) Below is my designed 11.1 to 5V buck converter in MATLAB Simulink.

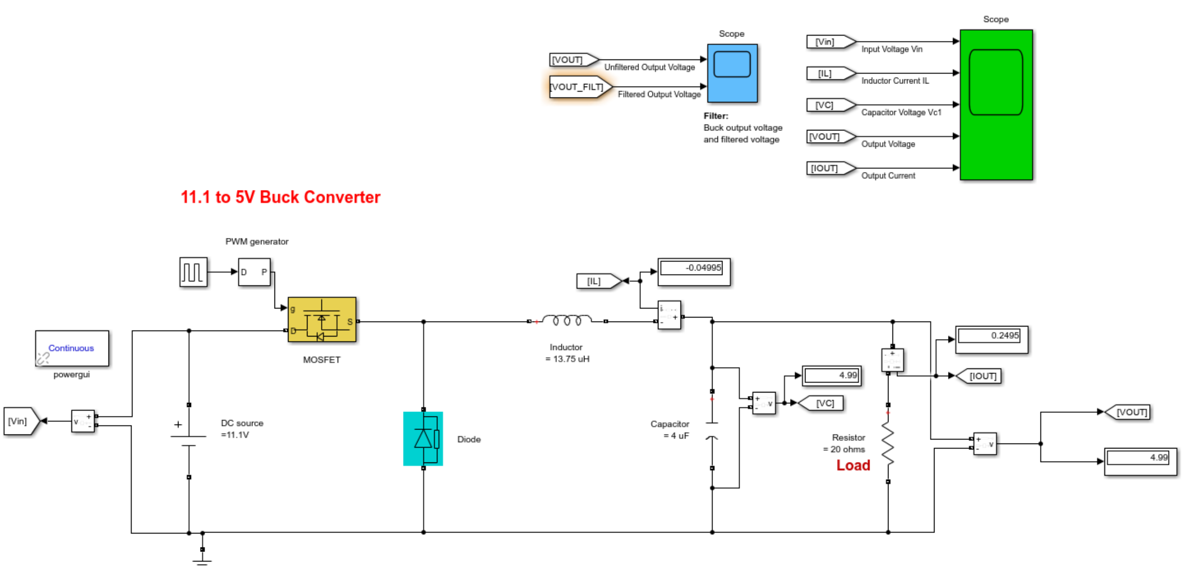

Figure 5: Designed 11.1 to 5V buck converter in MATLAB Simulink

System Outputs:

- $V_{out} = 4.99V$
- $I_{out} = 0.2495V$

Compared to my calculated outputs in Part 1, my simulated outputs are very close. My calculated output voltage is 5V, but my simulation produced 4.99V. My calculated output current is 0.25A, but my simulation produced 0.2495A. The likely reason for is that the diode and MOSFET have internal resistances of their own in MATLAB which could cause a slight difference from the calculated outputs. Aside from this, the Simulink-based system performs as expected.

<u>Analysis and reduction of harmonics:</u>

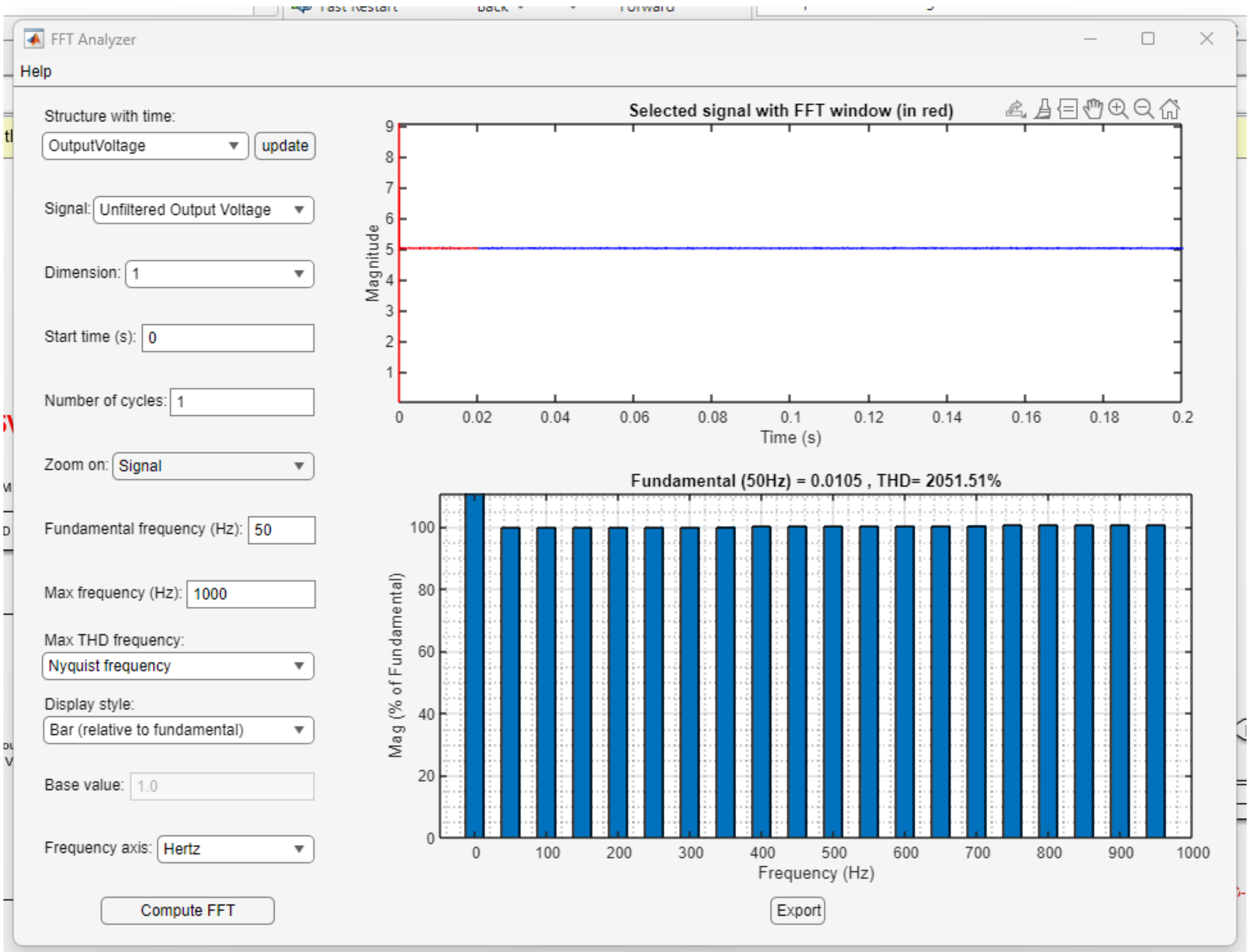

Figure 6: FFT Analyzer

<u>Reduction of harmonics:</u>

For a cutoff after the 5th harmonic, 500,000*5 = 2.5MHz

$$fc = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(0.8\mu H)(5\mu F)}} = 2.516\ MHz\ (cutoff\ after\ 5th\ harmonic)$$

$$H(s) = \frac{1/sC}{\frac{1}{sC} + sL} = \frac{1}{1 + s^2 LC} = \frac{1}{1 + s^2(0.8\mu)(5\mu)}$$

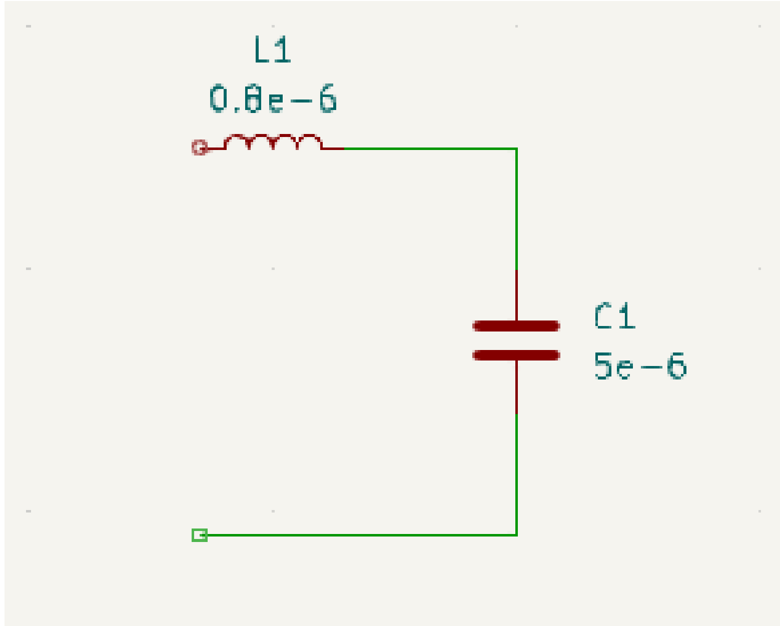

Figure 7: LC Filter Circuit

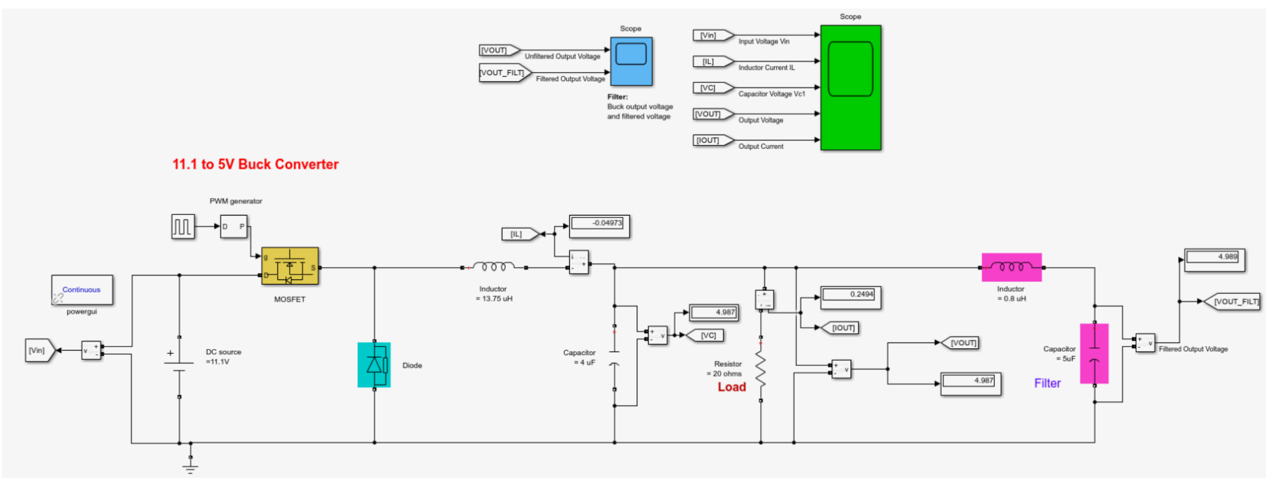

Figure 8: Buck Converter with LC Filter